RARE EARTHS

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In 2002, rare-earth production was primarily from the rare-earth mineral bastnäsite. Rare-earth ores were mainly supplied by China, with lesser amounts mined in Brazil, India, Russia, and the United States. Domestic demand decreased for rare earths used in petroleum fluid cracking catalysts and in rare-earth phosphors for television, x-ray intensifying, and fluorescent and incandescent lighting. Consumption was estimated to have decreased as imports of rare-earth alloys, compounds, and metals declined. Production of bastnäsite continued in the United States with subsequent production of cerium concentrates on a limited scale. U.S. imports of cerium compounds decreased (table 1).

Yttrium demand decreased by about 29.4% in 2002 compared with that of 2001, according to data from the PIERS database of The Commonwealth Business Media, Inc. Yttrium was used primarily in lamp and cathode-ray tube phosphors; lesser amounts were used in structural ceramics and oxygen sensors.

The domestic use of scandium increased slightly in 2002. Overall consumption of the commodity remained small. Commercial demand decreased as the domestic economy slowed. Demand was primarily for aluminum alloys used in baseball and softball bats. Scandium alloys, compounds, and metal were used in analytical standards, metallurgical research, and sporting goods equipment. Minor amounts of high-purity scandium were used in semiconductors and specialty lighting.

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium, and yttrium. The elements range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements in the Earth's crust at 60 parts per million (ppm), to thulium and lutetium, the least abundant rare-earth elements at about 0.5 ppm (Mason and Moore, 1982, p. 46). In rock-forming minerals, rare earths typically occur in compounds as trivalent cations in carbonates, oxides, phosphates, and silicates.

The lanthanides comprise a group of 15 elements with atomic numbers 57 through 71 that include the following, in order of atomic number: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Cerium, which is more abundant than copper (whose average concentration in the Earth's crust is 50 ppm), is the most abundant member of the group at 60 ppm, followed, in decreasing order, by yttrium at 33 ppm, lanthanum at 30 ppm, and neodymium at 28 ppm. Thulium and lutetium, the least abundant of the lanthanides at 0.5 ppm, occur in the Earth's crust in higher concentrations than antimony, bismuth, cadmium, and thallium.

Scandium, whose atomic number is 21, is the lightest rare-earth element. It is the 31st most abundant element in the Earth's crust, with an average crustal abundance of 22 ppm (Mason and Moore, 1982, p. 46). Scandium is a soft, lightweight, silvery-white metal, similar in appearance and weight to aluminum. It is represented by the chemical symbol Sc and has one naturally occurring isotope. Although its occurrence in crustal rocks is greater than lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities because it does not selectively combine with the common ore-forming anions.

Yttrium, whose atomic number is 39, is chemically similar to the lanthanides and often occurs in the same minerals as a result of its similar ionic radius. It is represented by the chemical symbol Y and has one naturally occurring isotope. Yttrium's average concentration in the Earth's crust is 33 ppm and is the second most abundant rare earth in the Earth's crust. Yttrium is a bright silvery metal that is soft and malleable, similar in density to titanium.

The elemental forms of rare earths are iron gray to silvery lustrous metals that are typically soft, malleable, ductile, and usually reactive, especially at elevated temperatures or when finely divided. Melting points range from 798° C for cerium to 1,663° C for lutetium. The unique properties of rare earths are used in a wide variety of applications. The principal economic rare-earth ores are the minerals bastnäsite, loparite, and monazite and lateritic ion-adsorption clays (table 2).

The rare earths were discovered in 1787 by Swedish Army Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine near the village of Ytterby, Sweden (Weeks and Leicester, 1968, p. 667). Because they have similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated from the mineral ytterbite by Finnish chemist Johann Gadolin (Weeks and Leicester, 1968, p. 671).

Rare earths were first produced commercially in the 1880s in Sweden and Norway from the rare-earth mineral monazite. Production in Scandinavia was prompted by the invention in 1884 of the Welsbach incandescent lamp mantle, which initially required the oxides of lanthanum, yttrium, and zirconium, with later improvements requiring only the oxides of thorium and cerium. The mantles also used small amounts of neodymium and praseodymium oxides as an indelible brand name label. The first rare-earth production in the United States was recorded in 1893 in North Carolina; however, a small tonnage of monazite was reportedly mined as early as 1887. South Carolina began production of monazite in 1903. Foreign production of monazite occurred in Brazil as early as 1887, and India began recovery of the ore in 1911.

Production

In 2002, one mining operation in California accounted for all domestic bastnäsite concentrate production. Molycorp, Inc. (a wholly owned subsidiary of Unocal Corporation) processed previously mined bastnäsite-bearing ore at its open pit operations at Mountain Pass, CA. Production was estimated to be 5,000 metric tons (t) of rare-earth oxides (REOs) of bastnäsite. In 2002, the minerals sector of Unocal reported sales revenue of $31 million (unaudited), an increase of $3 million from the $28 million (unaudited) in 2001 (Unocal Corporation, 2003, p. 139). Unocal's minerals sector included minerals other than the lanthanides (i.e. carbon, molybdenum, and niobium) and is undifferentiated in Unocal's report. Although the company was not actively mining, its mill was operated, and several lanthanide products were packaged, sold, and shipped. Substantial stocks of lanthanide concentrates and intermediate and refined compounds were available.

Based on economic conditions, Molycorp was prepared to restart its rare-earth refining operations. Ongoing programs to further develop the mine include filing an environmental impact report, the building of evaporation ponds, decommissioning of an old tailings pond, and developing a plan for a new tailings pond with an environmentally aware reduced water use fill technology.

Lanthanide products available in 2002 from Molycorp were bastnäsite concentrate, cerium nitrate, lanthanum chloride, lanthanum hydrate, lanthanum-rich nitrate, and the oxides of cerium, erbium, europium, gadolinium, praseodymium, samarium, and yttrium.

Molycorp has continued to decommission and decontaminate its closed rare-earth processing facilities at Washington and York, PA. Limited amounts of naturally occurring low-level radioactive material (thorium) were planned for removal to approved disposal sites. Provisions for additional disposal costs were recalculated at yearend 2002 and were $15 million lower than the costs estimated at yearend 2001 (costs include non-rare-earth locations, such as the Guadalupe oilfield in California) (Unocal Corporation, 2003, p. 50).

Two companies processed intermediate rare-earth compounds to lanthanides in 2002. Molycorp, which ceased production of refined compounds at its separation plant at Mountain Pass in 1998, continued to produce bastnäsite concentrate at its mill in 2002 and produced several intermediate compounds. Grace Davison (a subsidiary of W.R. Grace & Co.) processed intermediate rare-earth compounds to produce cerium- and lanthanum-rich compounds used in making fluid cracking catalysts for the petroleum industry.

Santoku America, Inc. (a subsidiary of Santoku Corporation of Japan) produced rare-earth magnet and rechargeable battery alloys at its operations in Tolleson, AZ. Santoku America produced both types of high-strength permanent magnets, namely neodymium-iron-boron (NIB) and samarium-cobalt. For the rechargeable battery industry, Santoku produced nickel-metal hydride (Ni-MH) alloys that incorporate specialty rare-earth mischmetals. The plant also produced a full range of high-purity rare-earth metals in cast and distilled forms, foils, and sputtering targets, including scandium and yttrium. Santoku Corporation (33%) continued its joint venture Anan Kasei Ltd. with Rhodia Electronics and Catalysis, Inc. (67%) in producing fuel additive emission-reduction catalyst, phosphors, polishing compounds, rare-earth-based nontoxic colorants and coatings for plastics, and three way catalytic converter catalysts.

Rhodia's operations produced finished rare-earth products from imported materials at its plant in Freeport, TX. Rhodia continued to operate its large-scale rare-earth separation plant in La Rochelle, France, and had additional capacity at its joint venture in Kobe, Japan. These plants provide Rhodia's U.S. operations with a majority of their rare-earth supply.

In 2002, Grace Davison announced the development of two new fluid cracking catalysts (FCCs), released under the trade names AdVanta™ and SATURN™. W.R. Grace and ExxonMobil Research and Engineering Co. announced an agreement to license patents held by ExxonMobil to Grace Davison to manufacture and market the rare-earth-containing AdVanta™ FCC (W.R. Grace & Co., 2002a). The catalyst provides superior stability and yields in the catalytic cracking process compared to other FCCs and has been in use at several ExxonMobil Corporation refineries worldwide

The SATURN™ catalyst was developed by Grace Davison as a sulfur reduction catalyst. In its first commercial application, it achieved a 50% to 60% reduction in sulfur at the Montana Refining Company, Great Falls, MT. The reduction in sulfur will help certain refineries meet the U.S. Environmental Protection Agency's Tier 2 reduction in sulfur emissions from gasoline. The Tier 2 plan was legislated to control and reduce air pollution from passenger cars and light trucks. The rare-earth-containing SATURN™ catalyst is reportedly costly to produce; however, its use will likely offset alternative refinery capital expenditures that would have been needed to meet the Tier 2 requirements (W.R. Grace & Co., 2002b).

Essentially all purified yttrium was derived from imported compounds. The minor amounts of yttrium contained in bastnäsite from Mountain Pass, CA, are not recovered as a separate product.

Two scandium processors operated in 2002. High-purity products were available in various grades, with scandium oxide produced at up to 99.999% purity. Boulder Scientific Co. processed scandium at its Mead, CO, operations. It refined scandium primarily from imported oxides to produce high-purity scandium compounds, including carbide, chloride, diboride, fluoride, hydride, nitride, oxalate, and tungstate.

Scandium also was purified and processed from imported oxides at Aldrich-APL, LLC in Urbana, IL, to produce high-purity scandium compounds, including anhydrous and hydrous chloride, fluoride, iodide, and oxide. The company also produced high-purity scandium metal.

The principal domestic producers of NIB magnet alloys were Magnequench International, Inc. (MQ), Anderson, IN, and Santuko America, Inc., Tolleson, AZ. The leading U.S. producers of rare-earth magnets were Crumax Magnetics, Inc., Elizabethtown, KY; Electron Energy Corporation, Landisville, PA; Magnequench UG (previously Ugimag, Inc.), Valparaiso, IN; MQ, Anderson, IN; and Magnetic Materials Division of Hitachi Metal America, Ltd., Edmore, MI, and China Grove, NC.

Demand increased for rare earths used in Ni-MH batteries. The rechargeable batteries are used in cellular phones, portable computers, PDAs, camcorders, and other portable devices. Japan, the leading producer, shipped 654 million units in 2001, a 64% decrease compared with 2000 (Roskill's Letter from Japan, 2002). Ni-MH batteries were the leading rechargeable battery product, followed by nickel-cadmium and lithium-ion types. Shipments from Japan of nickel-cadmium and lithium-ion batteries also decreased.

Consumption

Statistics on domestic rare-earth consumption were developed by surveying various processors and manufacturers, evaluating import and export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths decreased in 2002 compared with that of 2001. Domestic consumption of rare-earth metals and alloys also decreased in 2002, especially for those used in permanent magnets and rechargeable batteries.

Based on information supplied to the U.S. Geological Survey (USGS) by U.S. rare-earth refiners and selected consumers and an analysis of import data, the approximate distribution of rare earths by use was as follows: automotive catalytic converters, 14%; glass polishing and ceramics, 30%; metallurgical additives and alloys, 19%; permanent magnets, 3%; petroleum refining catalysts, 28%; rare-earth phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 3%; and miscellaneous, 3%.

In 2002, domestic yttrium consumption was estimated to have decreased to 334 t from 473 t in 2001. Yttrium information was based on data retrieved from the PIERS database. Yttrium compounds and metal were imported from several sources in 2002. Yttrium was imported from China (69.9%), Japan (18.6%), Germany (5.4%), the Netherlands (4.7%), and the United Kingdom (1.4%). The estimated use of yttrium, based on imports, was primarily in lamp and cathode-ray tube phosphors (78.7%), lasers and electronics (10.3%), ceramics and oxygen sensors (10.0%), alloys (0.4%), and miscellaneous (0.6%).

Stocks

All U.S. Government stocks of rare earths in the National Defense Stockpile (NDS) were shipped in 1998. Periodic assessments of the national defense material requirements may necessitate the inclusion of rare earths in the NDS at a future date.

Prices

The prices of rare-earth materials either increased or were essentially unchanged in 2002 compared with 2001. The following estimates of prices were based on trade data from various sources or were quoted by rare-earth producers. All rare-earth prices remained nominal and subject to change without notice. The competitive pricing policies in effect in the industry caused most rare-earth products to be quoted on a daily basis. The average price of imported rare-earth chloride was $1.43 per kilogram in 2002, a decrease from $1.61 per kilogram in 2001. In 2002, imported rare-earth metal prices averaged $8.25 per kilogram, a decrease from $12.17 per kilogram in 2001. Mischmetals and specialty mischmetals composed most of the rare-earth metal imports. (Mischmetal is a natural mixture of rare-earth metals typically produced by metallothermic reduction of a mixed rare-earth chloride.) The price range of basic mischmetal was from $5.00 to $6.00 per kilogram (in metric ton quantities) at yearend 2002, unchanged from the previous year (High Tech Materials, 2002§[1]). The average price for imported cerium compounds, excluding cerium chloride, increased to $5.03 per kilogram in 2002 from $4.92 per kilogram in 2001. The primary cerium compound imported was cerium carbonate.

The 2002 nominal price for bastnäsite concentrate was $3.64 to $4.08 per kilogram of lanthanide oxide contained ($1.65 to $1.85 per pound of lanthanide oxide contained). The price of monazite concentrate, typically sold with a minimum 55% rare-earth oxide, including thorium oxide content, free-on-board (f.o.b.) as quoted in U.S. dollars and based on the last U.S. import data, was unchanged at $400.00 per metric ton. In 2002, no monazite was imported into the United States. Prices for monazite remained depressed because the principal international rare-earth processors continued to process only thorium-free feed materials.

The nominal price for basic neodymium metal, published at yearend by High Tech Materials for metric ton quantities, decreased to the range of $8 to $20 per kilogram ($3.63 to $9.07 per pound), f.o.b. shipping point. Most neodymium-iron-boron alloy was sold with additions of cobalt (typically 4% to 6%) or dysprosium (no more than 4%). The cost of the additions was based on pricing before shipping and alloying fees; with the average cobalt price decreasing to $15.23 per kilogram ($6.91 per pound) in 2002, the cost would be about $0.15 per kilogram ($0.07 per pound) for each percentage point addition.

Rhodia quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 2002, are listed in table 3. No published prices for scandium oxide in kilogram quantities were available. Yearend 2002 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices were mixed from those of the previous year for most grades and were listed as follows: 99% purity, $700 per kilogram; 99.9% purity, $2,000 per kilogram; 99.99% purity, $2,500 per kilogram; and 99.999% purity, $3,200 per kilogram.

Scandium metal prices for 2002 were unchanged from those of 2001 and were as follows: 99.9% REO purity, metal pieces, distilled dendritic, ampouled under argon, $279 per 2 grams; 99.9% REO purity, metal pieces, ampouled under argon, $198 per gram; 99.9% purity, metal ingot, ampouled under argon, $218 per gram; and 99.9% REO purity foil, 0.025-millimeter (mm) thick, ampouled under argon, 25 mm by 25 mm, $111 per item (Alfa Aesar, 2001, p. 1284).

Scandium compound prices were as follows: scandium acetate hydrate 99.9% purity, $66.30 per gram; scandium chloride hydrate 99.99% purity, $85.00 per gram; scandium nitrate hydrate 99.9% purity, $73.90 per gram; and scandium sulfate pentahydrate 99.9% purity, $65.80 per gram. Prices for standard solutions for calibrating analytical equipment were $25.70 per 100 milliliters of scandium

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[1]References that include a section mark (§) are found in the Internet References Cited section.

atomic absorption standard solution and $420.30 per 100 milliliters of scandium plasma standard solution (Aldrich Chemical Co., 2002, p. 1639-1641).

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost of the oxide, and higher purity distilled scandium metal prices have averaged about five times that cost.

Foreign Trade

U.S. imports and exports of rare earths declined in 2002 compared with those of 2001. Data in this section are based on gross weight, while data in the tables may be converted to equivalent rare-earth oxide, as noted. U.S. exports totaled 8,350 t valued at $49.8 million, a 9.9% decrease in quantity and a value that was essentially the same when compared with those of 2001 (table 4). Imports totaled 19,800 t gross weight valued at $93.5 million, a 26.8% decrease in quantity and a 33.1% decrease in value compared with those of 2001 (table 5).

In 2002, U.S. exports of rare earths decreased in all trade categories except rare-earth metals and ferrocerium and other pyrophoric alloys, which increased. Principal destinations in 2002, in descending order, were Germany, Canada, Japan, and the Republic of Korea. The United States exported 1,090 t of rare-earth metals valued at $5.9 million, a 47% increase in quantity compared with that of 2001. Principal destinations, in descending order of quantity, were Brazil and Japan, with smaller amounts to China, the United Kingdom, and Singapore. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, decreased by 33.4% to 2,740 t valued at $13.9 million. Major destinations, in descending order of quantity, were the Republic of Korea, Japan, Germany, and Malaysia.

Exports of inorganic and organic rare-earth compounds decreased 16.2% to 1,340 t in 2002 from 1,600 t in 2001, and the value of the shipments increased by 21.3% to $21.2 million. Shipments, in descending order of quantity, were to Japan, Canada, Germany, and Austria.

U.S. exports of ferrocerium and other pyrophoric alloys increased to 3,180 t valued at $8.86 million in 2002 from 2,820 t valued at $7.93 million in 2001. Principal destinations, in descending order of quantity, were Canada, Germany, Japan, and Mexico.

In 2002, U.S. imports of compounds and alloys decreased for six out of seven categories, as listed in table 5. China and France dominated the import market, especially for mixed and individual rare-earth compounds, followed by Japan and India (figure 1).

Imports of cerium compounds totaled 3,800 t valued at $19.1 million. The quantity of cerium compounds imported decreased by 34% as a result of decreased demand for automotive exhaust catalysts. China was the major supplier for the eighth consecutive year, followed by France, Japan, and Austria.

Imports of yttrium compounds that contain between 19 and 85 weight-percent oxide equivalent (yttrium concentrate) decreased by 43.5% to 73,300 kilograms (kg) in 2002, and the value decreased by 10.1% to $3.87 million. China was the leading supplier of yttrium compounds, followed by Japan and France.

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, decreased by 20.7% compared with those of 2001. Rare-earth compound imports decreased to 9,670 t valued at $49.2 million. The major sources of individual rare-earth compounds, in decreasing order, were China, France, Estonia, and Russia. Imports of mixtures of rare-earth oxides, other than cerium oxide, decreased by 48.9% to 1,040 t valued at $4.5 million. The principal source of the mixed rare-earth oxides was China, with much smaller quantities imported from Japan, the United Kingdom, and Austria. Imports of rare-earth metals and alloys into the United States totaled 1,210 t valued at $9.99 million in 2002, a 2.3% increase in quantity compared with those of 2001. The principal rare-earth metal sources, in descending order of quantity, were China and Japan. Metal imports were essentially unchanged from the previous year in which they declined by 43%. In 2002, imports of rare-earth chlorides decreased by 30.2% to 3,920 t valued at $5.6 million. Supplies of rare-earth chloride, in descending order of quantity, came from China and India, with minor amounts from France and the United Kingdom. In the United States, rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts. Imports of ferrocerium and pyrophoric alloys decreased to 101,000 kg valued at $1.21 million. Principal sources of these alloys, in descending order of quantity, were China and Austria.

World Review

China, France, India, and Japan were major import sources of rare-earth chlorides, nitrates, and other concentrates and compounds (table 5). Thorium-free intermediate compounds as refinery feed were still in demand as a result of industrial consumers expressing concerns with the potential liabilities of radioactive thorium, the costs of complying with environmental monitoring and regulations, and costs at approved waste disposal sites. In 2002, demand for rare earths decreased in the United States, and imports decreased by 27%.

In 2002, estimated world production of rare earths increased to 98,200 t of REOs (table 6). Production of monazite concentrate was estimated to be 5,700 t (table 7).

World reserves of rare earths were estimated by the USGS to be 88 million metric tons (Mt) of contained REOs in 2002. China, with 31%, had the largest share of those world reserves. China's reserves are primarily contained in bastnäsite-bearing carbonatites and REE carbonatite/hydrothermal iron-oxide deposits. Australia's reserves include rare earths contained in monazite; owing to its widespread availability as a very low-cost byproduct of heavy-mineral sands processing, however, thorium-free ores have precluded its use in most parts of the world. Australia's other major reserve of rare earths is in the Mount Weld carbonatite.

Austria.—Treibacher Industrie AG acquired a 25% interest in Estonian company AS Silmet, a rare-earth processing and metallurgical company in Sillamäe. Treibacher has the option to acquire an additional 25% holding in Silmet if economic or mutual interests of the companies are favorable. Both companies have expertise in rare-earth chemicals, metallurgy, and processing (Treibacher Industrie AG, undated§).

Treibacher sells a full range of rare-earth products, including all of the oxides, ferrocerium/lighter flint alloys, hydrogen storage alloys, individual rare-earth metals, mischmetal and 15 different cerium compounds and solutions.

Australia.—Lynas Corporation Ltd. continued with development of its Mount Weld rare-earth deposit 30 kilometers south of Laverton, Western Australia (Matthew James, Lynas Corp. Ltd., June 17, 2003, oral commun.). Measured reserves at Mount Weld are 1.2 Mt grading 15.7% REOs and indicated reserves are an additional 5 Mt grading 11.8% REOs. Inferred resources are 1.5 Mt grading 9.9% REOs. The light-group rare-earth elements (LREEs) deposit has an expected mine life of at least 20 years with a rare-earth cutoff grade of 4%. Naturally occurring radioactive mineral content at Mount Weld is a low 0.05%. In March, Lynas commenced operation of a pilot plant at the site. Future plans are to build a flotation plant at the mine site to produce 32,500 t of REO concentrate per year. Concentrate from the mill will initially be sent to China to produce 26,000 metric tons per year (t/yr) of a 45% REO rare-earth carbonate on a toll basis. Separated rare-earth compounds are also planned for production in China with a capacity of 10,500 t/yr.

Australia remained one of the world's major potential sources of rare-earth elements from its alkaline intrusive deposit, heavy-mineral sands, and rare-earth lateritic deposits. Monazite is a constituent in essentially all of Australia's heavy-mineral sands deposits. It is normally recovered and separated during processing but, in most cases, is either returned to tailings because of a lack of demand or stored for future sale. In 2002, major producers of heavy-mineral sand concentrates in Australia, in order of production, were Iluka Resources, Ltd., Tiwest Joint Venture, Consolidated Rutile, Ltd. (CRL) (43% owned by Iluka Resources Ltd.), RZM/Cable Sands, Ltd. (CSL), Mineral Deposits Ltd. (MDL), Currumbin Minerals Pty. Ltd., and Murray Basin Titanium Pty. Ltd. (Mineral Sands Report, 2003).

Australia Zirconia Ltd. (AZL) (a wholly owned subsidiary of Alkane Exploration Ltd.) revised its resource estimate for the Dubbo zirconia-rare earth deposit in New South Wales to 37.5 Mt. The alkaline intrusive ore, an altered trachyte, grades 1.96% zirconium oxide, 0.745% rare-earth oxides, 0.46% niobium oxide, 0.14% yttrium oxide, and 0.04% hafnium oxide, and 0.03% tantalum oxide (Industrial Minerals, 2002f).

Iluka operated eight mines in Australia (six on the west coast and two on the east coast) and two in the United States. Iluka's Australian subsidiary WA Titanium Minerals operated six mines and a zircon finishing plant (Narngulu) in Western Australia in 2002. Two new mines near Eneabba, Western Australia—the South Tails and Depot Hill deposits were planned for development in the first half of 2003 (Iluka Resources Limited, 2003§).

Iluka's other mining operations in Western Australia were the North West Mine near Capel, the North Mine and South Mine near Eneabba, and the Yoganup, Yoganup Extended, and Busselton Mines in the southwestern region. Mining of the remnants of the Yoganup Extended Mine were scheduled to begin in early 2003.

Iluka's 50%-owned two east coast mines, the Yarraman and Ibis, were operated by CRL on North Stradbroke Island, New South Wales. Production was lower because of lower grades at Yarraman and operating problems with the tailings circuit (Iluka Resources Limited, 2003§). The tailings circuit was upgraded in late 2002 with improved production rates and recoveries expected in 2003. CRL's Ibis Mine was scheduled for closure because the company shifted production to its Enterprise deposit in New South Wales. The dredge and infrastructure at Ibis are scheduled for shipment to the Enterprise location in 2003. CRL's overall production for 2003 was expected to be lower because of the move. CRL operated a dry separation plant at Pinkenba, Brisbane, Queensland.

Iluka increased its total heavy-mineral resources by 15%, while its heavy-mineral reserves increased by 14% (Iluka Resources Limited, 2003§). In the Murray Basin deposit area of New South Wales and Victoria, Iluka increased its resources of economic heavy-minerals by 28% (Iluka Resources Limited, 2002). The increase is primarily the result of adding three new deposits—the Boulka (near Ouyen), the Dispersion, and the Snapper. The Dispersion deposit in New South Wales has a resource of 7.3 Mt grading 22% heavy minerals with a 15% zircon content. The 10 Ouyen deposits have a reported total resource of about 60 Mt grading 15.7% heavy minerals. The Snapper deposit has a resource of 5.111 Mt grading 13.8% heavy minerals (Iluka Resources Limited, 2002).

Iluka purchased a 100% interest in Basin Minerals Limited (BML) in the Murray Basin (Iluka Resources Ltd., 2003, p. 5). Iluka paid A$139 million in June for BML's extensive heavy-mineral sands interests, including the Culgoa and Douglas deposits. BML's major deposit includes the Douglas mineral-sands project in southwestern Victoria. Iluka planned initial development of the Douglas deposit in the last half of 2003. The Douglas deposit covers an area of 5,860 square kilometers and has a reported resource of 22.4 Mt of heavy minerals. Five strandline deposits within the Douglas deposit contain 14.18 Mt of economic heavy minerals (Mineral Sands Report, 2002).

BeMaX Resources N.L. (75%) and Probo Mining Pty. Ltd. (25%) announced they would begin development of their Ginkgo Mineral Sands Project (Ginkgo), 120 kilometers (km) north of Mildura, Victoria, in the Murray Basin near Pooncarie, New South Wales. The partners announced that they had obtained mining leases (Industrial Minerals, 2002d). A bankable feasibility study was completed and approval to develop the deposit was received from the New South Wales Minister of Planning (Industrial Minerals 2002a). Reserves are 184 Mt of ore grading 3.2% heavy minerals. Reserve estimates were increased by 21% to a revised 40 Mt with a mine life of 25 years. Production from the Ginkgo deposit was expected to commence in late 2003 with shipments emanating in early 2004. A heavy-mineral production rate of 285,000 t/yr was planned (BeMaX Resources N.L., 2002; Industrial Minerals, 2002a).

Southern Titanium N.L. reported that it was acquiring working capital to develop its recently acquired Mindarie deposit in the Murray Basin (Industrial Minerals, 2002b). Funding was to be used to complete a bankable feasibility study, bonds for purchasing mine and plant equipment, and other obligations. Southern obtained 100% of the Mindarie deposit from Steiner Holdings Pty. Ltd. Production from the Mindarie was expected to begin in 2004 (Huleatt, Jaques, and Towner, 2003).

Doral Mineral Sands Pty. Ltd. opened its $30 million Dardanup Mine in Western Australia on October 8 (Huleatt, Jaques, and Towner, 2003). Capacity at the operation, which is 15 km east of Bunbury, was 120,000 t/yr of titanium minerals and 10,000 t/yr of zircon.

Brazil.—Reserves of rare earths were 109,000 t contained in various types of deposits, including alkaline intrusives, carbonatites, fluvial or stream placers, lateritic ores, and marine placers. The reserves, comprising measured and indicated quantities of monazite, were distributed in deposits primarily in the States of Rio de Janeiro (24,570 t), Bahia (10,186 t), and Espírito Santo (4,136 t) (Fabricio da Silva, 2002). The main placer reserves were in the States of Minas Gerais (24,396 t), Espírito Santo (11,372 t), and Bahia (3,481 t). In 2001, total reserves of rare earths in Brazil were about 6 Mt grading 0.5% REOs contained. Brazil did not produce rare earths in 2001, the latest year for which Government data were available (Fabricio da Silva, 2002).

China.—Production of rare-earth concentrates in China was 80,600 t of REOs in 2001, the latest year for which reported data were available (table 6). Refined and processed products reached 71,000 t of REOs, including production of individual high-purity rare-earth product, which accounted for 36,000 t of the total. Concentrate production in 2001 was 10.4% higher than in 2000. Consumption within China increased by 17% in 2001 to about 22,600 t of REOs. Permanent magnets and phosphors, the major domestic use, consumed 6,300 t of equivalent REOs. Metallurgical applications, the second largest sector, consumed 5,500 t of equivalent REOs, up by 5.7% from the 2000 level (China Rare Earth Information, 2002).

Production of rare-earth magnets in 2001 was 8,650 t, distributed between 8,000 t of NIB magnets, 500 t of bonded NIB magnets, and 150 t of samarium-cobalt magnets. Phosphors consumed 1,100 t of material for television and lamps, using 750 t of equivalent REOs. Rechargeable NiMH battery alloys that contain rare earths consumed 1,200 t of REOs in the manufacture of 300 million batteries. Other major consuming rare-earth sectors in 2001 were 2,900 t in glass and ceramics, 3,400 t in agriculture, 4,500 t in catalysis and oil cracking catalysts, and 5,500 t in metallurgy and machinery (China Rare Earth Information, 2002).

Jiangxi Rare Earth Metal Tungsten Group Co. and the city of Ganzhou have formed the joint venture Jiangxi Rare Earth Group to explore for rare earths in southern China. Located in Ganzhou, the company had capital of Y350 million (US$42.3 million). The city of Ganzhou contributed Y170 million, and Jiangxi Rare Earth Metal Tungsten group provided Y180 million to fund the venture (China Rare Earth News, 2002§).

Estonia.—AS Silmet (a subsidiary of AS Silmet Group) separated rare earths at its plant in Sillamäe. Located on the northeastern coast of Estonia on the Gulf of Finland, Silmet operates three plants—a rare earth separations plant, a rare metals production plant, and a metallurgical factory for producing alloys. The separation plant has capacity of 3,000 t/yr of rare-earth compounds, and the metals plant, a capacity of 700 t/yr. Rare-earth processing at the facility started in 1970 (AS Silmet Group, undated§).

Treibacher Industrie AG of Austria acquired a 25% interest in AS Silmet and negotiated an option to acquire an additional 25% of Silmet if economic conditions warrant further investment (AS Silmet Group, 2002§). Treibacher's rare-earth unit Treibacher Auermet Produktions GMBH produces several rare-earth alloys, compounds, and metals at its facilities in Austria.

France.—Rhodia Electronics & Catalysis announced the startup of its Eolys™ production unit to reduce diesel particulate emissions to the environment (Rhodia Electronics & Catalysis, 2002). Rhodia partnered with Peugeot Citroën, to develop the emission system using Eolys™. The Eolys™ system has been extensively tested on the Peugeot 607 HDi direct injection diesel engine and has resulted in the elimination of 99.9% of particulates. This equates to 0.001 gram of particulates per kilometer driven. The exhaust emission system has been installed on the Peugeot 307, 406, 607 and the Citroën C5.

India.—Indian Rare Earth Ltd. (IRE) operates three heavy-mineral sand mines at Chavara in Kerala State, Manavalakurichi in Tamil Nadu State, and the Orissa Sands Complex in Orissa State. In 2002, IRE recovered and processed monazite to produce thorium-free rare-earth chloride and byproduct thorium hydroxide.

Kerala Minerals and Metals Ltd. (KMML) mined and processed heavy-mineral sands from beach sands along the Chavara coast in Kerala State. KMML announced that it was building a new mineral separation plant to increase capacity to about 3 million metric tons per year (Mt/yr) of ilmenite, with concomitant increases in the other heavy minerals. Monazite from the KMML deposits on the Chavara coast had an average composition of 57.5% REOs with 7.96% thorium oxide and 28.2% phosphate, with a specific gravity of 5.14 (Kerala Minerals and Metals Ltd., undated§). The heavy-mineral sands of the coast and adjoining seabeds contained 240 Mt of ilmenite, 60 Mt of sillimanite, 50 Mt of zircon, 20 Mt of rutile, and 4 Mt of monazite.

Japan.—Japan refined 5,423 t of rare earths in 2002, an increase from the 5,104 t produced in 2001. The rare earths were produced from imported ores and intermediate raw materials. Imports of rare earths during the year were 22,571 t, an increase from the 19,736 t imported in 2001. The value of imports, however, decreased by 14% to $16,457 million in 2002 from $18,600 million in 2001 (Roskill's Letter from Japan, 2003c). Japanese rare-earth imports declined for lanthanum oxide and rare-earth compounds (including intermediate raw materials) and increased for cerium oxide, other cerium compounds, ferrocerium, rare-earth metals, and yttrium oxide. Imports from the United States decreased to 512 t in 2002 from 664 t in 2001.

Estimated production of Japanese bonded rare-earth magnets in 2002 was 500 t, a decrease from the 591 t produced in 2001 (Roskill's Letter from Japan, 2003b). After a decade of double-digit growth, the decrease in NIB magnet production is the third decline in 3 years. Demand also decreased for non-rare-earth bonded magnets. Production of rare-earth magnets, including sintered and bonded types was 4,636 t for 2002, valued at 52,484 million yen (Roskill's Letter from Japan, 2003a)

Japanese imports of rare earths from China were as follows: cerium compounds, 5,651 t; rare-earth metals, 4,947 t; cerium oxide, 3,621 t; rare-earth compounds, 3,513 t; lanthanum oxide, 1,119 t; yttrium oxide, 884 t; and ferrocerium, 54 t (Roskill's Letter from Japan, 2003b).

Total imports in 2002 were 22,571 t classified as follows: other cerium compounds, 6,225 t; rare-earth metals, 4,985; rare-earth compounds, 4,463 t; cerium oxide, 4,161 t; lanthanum oxide, 1,315 t; yttrium oxide, 917 t; and ferrocerium, 505 t (Roskill's Letter from Japan, 2002b). No rare-earth chlorides were imported in 2002. China continued to be the leading source of rare-earth imports for Japan with 19,789 t in 2002, an increase from the 15,461 t imported in 2001.

Kenya.—Tiomin Resources Inc. announced that it was awarded a mining lease from the Kenyan Mining and Prospecting Licensing Committee for its Kwale heavy-mineral sands project. The mining lease is valid for 16 years and allows for a 10-year extension. The Kwale project is expected to generate socioeconomic benefits to the region through the formation of direct and indirect employment, road and communication infrastructure, and skill development (Tiomin Resources Inc., 2002§). Resources at Kwale are 200 Mt of heavy-mineral sands containing 3.8 Mt of ilmenite, 1.1 Mt of rutile, 0.6 Mt of zircon, and lesser amounts of monazite.

Korea, North.—Formed in 1988, Korea International Chemical Joint Venture Company (or Chosun International Chemicals Joint Operation Co. or Choson International Chemicals Joint Operation Co.) was created to process and refine rare earths from monazite. The plant was reportedly designed using solvent extraction technology from China's Yue Long Chemical Plant near Shanghai. The North Korean plant was completed in April 1990 in Hamhung, and production began in 1991. Monazite feed for the plant is mined at the Ch'olsan Uranium Mine near Ch'olsan-kun, P'yong'an Province. The operation was reportedly closed in 1997 but was reported to be operating in November 2002 by the Korean Central News Agency. The Hamhung plant has the capacity to process 1,500 t/yr of monazite with an output of 400 t/yr of rare-earth metals and oxides (Nuclear Threat Initiative, 2003§).

Kyrgyzstan.—The Kutessai II rare-earth deposit contains a complex ore. The rare-earth content of the Kutessai ore is enriched in the heavy rare earths with LREEs constituting 54.5%, heavy-group rare-earth elements (HREE) constituting 43.7%, and 1.8% constituting losses during analysis (moisture, volatiles). Reserves at Kutessai II are 20.2 Mt ore with an average grade of 0.25% rare earths. Total rare earths in the deposit are 51,500 t (Geological Survey of Kyrgyzstan, undated§).

Malawi.—The Kangankunde rare-earth and strontianite deposit is being developed by Rift Valley Resource Developments Ltd. The deposit is an intrusive carbonatite located 90 km north of Blantyre. Rising 200 meters above the plains, Kangankunde contains 11 Mt of ore with proven resources of 6 Mt. The deposit grades 8% strontianite and 2.6% hard-rock monazite. Phase 1 of the development is to produce 30,000 t of ore and recover 20,000 t/yr of strontium carbonate. Phase 2 is scheduled to produce a monazite concentrate (Industrial Minerals, 2002c).

Madagascar.—QIT Madagascar Minerals S.A. (QMM), owned by Rio Tinto Iron and Titanium Inc. (RIT) (80%) and the Malagasy Government (20%), announced that it had received environmental permits (end of 2001) for a proposed heavy-mineral sands deposit in southeastern Madagascar. QMM was granted the permits after 3½ years of negotiations. In 2001, RIT started its feasibility study on mining heavy-mineral sands near Tolagnaro (Fort Dauphin) in southeastern Madagascar and proceeded with the next phase in 2002 with market and engineering studies (Industrial Minerals, 2002e).

Mozambique.—Kenmare Resources plc of Dublin, Ireland, issued an invitation to bid for the construction of its proposed Moma heavy-mineral sands project. The invitation proposes a 2-year timetable from signing to commissioning of the Moma mine and processing facilities (Kenmare Resources plc, 2002§).

Russia.—Solikamsk Magnesium Works (SMZ) reported that it has been producing rare-earth chlorides from loparite concentrate, equivalent to 3,000 to 4,000 t of REOs. Previously it had sent the material to Estonia and Kazakhstan for separation and refining. SMZ announced that it was constructing a facility to process the material into 3,000 to 4,000 t of rare-earth carbonate. Phase two of SMZ's plan was to produce a 90%-to-96%-purity cerium carbonate or hydroxide, an 80%-to-98% lanthanum concentrate, and concentrates containing neodymium, praseodymium, and samarium. SWZ is also producing a master alloy of magnesium-zirconium-lanthanides containing 1.5%-to-35% zirconium, 2.5%-to-35% rare earths, and the remainder magnesium (Solikamsk Magnesium Works, 2003a§). SMZ's produces two mixed rare-earth compounds—a rare-earth chloride with a minimum content of 38% REOs and a rare-earth carbonate with a minimum content of 45% REOs (Solikamsk Magnesium Works, 2003b§).

In January, creditors of AO Sevredmet's Lovozero Mining Combine decided to auction off the bankrupt Lovozero loparite deposit in the Murmansk region. The starting price for the property was set at $6 million. The mine is the principal source of LREEs in Russia. The mining operation was controlled by AO Sevredmet's Lovozero Mining Combine until March 15, 2000, when Sevredmet went into receivership. The mining company restructured under OAO Sevredmet and formed the new public company Lovozero Mining Company (LMC). LMC operated the Umbrozero mining facility to produce loparite concentrate. To be more cost effective, LMC is considering increasing capacity to 2,000 metric tons per month (t/mo) from 1,000 t/mo. The principal problem is that SMZ can only process 1,000 t/mo. Talks reportedly began with Estonian rare-earth processor AS Silmet to restore its loparite processing equipment in Sillamäe. Presently, SMZ is the only consumer of loparite concentrate (Grechina, 2002§).

South Africa.—Rare Earth Extraction Co. Ltd. (RARECO) received funding of $16 million from the Industrial Development Corporation and was awaiting financing from an overseas investor. Development of the deposit at Steenkampskrall requires the refurbishment of the old Anglo American plc mine that was operated between 1952 and 1963 for its hard-rock monazite. RARECO has reportedly signed a 5-year agreement with a European company for two-thirds of Steenkampskrall's output. The balance of production not under contract will be placed on the spot market (Mining Weekly, 2002§).

Ticor South Africa joint-venture partners Ticor Ltd. of Australia (40%) and Kumba Resources Ltd. (60%) (a subsidiary of Iscor Ltd.) processed heavy-minerals at the Hillendale Mine in KwaZulu-Natal Province. The deposit, which is mined using water jets, has a high kaolinite clay content. The tailings design includes a special dam with multiple single discharge risers to control the properties of the non-Newtonian slurry. The tailings are treated with multiple deep-cone thickeners to produce high-density tailings. Underflow is pumped with positive displacement pumps to a thickened tailings dam (Patterson & Cooke, undated§). The Hillendale mine has reserves of 73 Mt of ore grading 5.6% heavy minerals.

Namakwa Sands (a wholly owned subsidiary of Anglo American) continued to increase production of heavy-mineral sands as a result of a R1.13 billion expansion at its mine at Brand-se-Baai. Reserves at the site are more than 500 million tons (MBendi Information Services (Pty) Ltd., 2002§).

Sri Lanka.—Production of heavy-mineral sands from the Pulmoddai mine is on hold until negotiations are completed between the Sri Lankan Government and the Tamil Tiger opposition. Shipments from the mine were expected to resume in 2003. The Government-owned Lanka Mineral Sands Ltd. has large stocks of mineral sands but has not sent bulk shipments since September 1997 when rebels sank a bulk carrier ship. Pulmoddai has a heavy-mineral content of 60% to 70%. Reserves at the deposit are expected to last 25 to 30 years (Industrial Minerals, 2002g).

Current Research and Technology

Etrema Products, Inc. (a wholly owned subsidiary of Edge Technologies, Inc. of Ames, IA) announced that it has developed a high-power ultrasonic system using rare earths to kill pathogens in the laboratory. Based on TERFENOL-D, an alloy of iron and the rare-earth elements terbium and dysprosium that expands or contracts with the application or removal of an external magnetic field, the ultrasonic system was able to kill bacteria, including coliform [Escherichia coli (E. coli), fecal coliform], streptococcus, and enterococcus. TERFENOL-D is also used in acoustic devices, actuators, sonar, and other smart materials for the oil and gas industry (Etrema Products, Inc., 2002b§).

Edge Technologies, Inc. announced that it launched a new subsidiary Shell Shocked Sound, Inc. (S3I) to develop and commercialize folded-shell speaker technology (FSST). The new technology will allow the development of smaller high-performance speakers based on the rare-earth material TERFENOL-D. FSST employs a three-dimensional module that eliminates the need for a speaker enclosure and is highly efficient, producing a greater volume from a given power input. The FSST technology is being developed for speakers by S3I, which licensed the original technology from the Canadian Defence Research Establishment, Atlantic (DREA) for use in sonar systems (Etrema Products Inc., 2002a§).

Etrema Products, Inc. was selected by the U.S. Department of the Navy to develop an improved process to produce high-grade TERFENOL-D for use in new improved sonar systems. The rare-earth material is presently made in two grades—production and research. Research-grade material performs 20% to 30% better than production-grade material as a giant magnetostrictive alloy, but the substantially higher cost to produce research-grade material has limited production. According to Etrema, until recently, it was believed that commercial quantities of research-grade TERFENOL-D could only be produced in the zero-gravity environment of space. Scientists at Etrema, however, have successfully tested a new process to produce research-grade material that they hope to scale-up with moderate modification of their existing production equipment (Etrema Products, Inc, 2002c§).

TERFENOL-D magnetostrictive actuators have been used to create high-frequency energy to vibrate commercial screening systems, like those used in the foundry, mining, and oil industries. Compared to mechanically driven screening systems, the rare-earth alloy system may eliminate blinding, a problem caused when screen openings get blocked by near-sized particles or material deposits. Research is continuing with a major screening manufacturer to optimize power and frequency for different applications (Etrema Products, Inc., 2002d§).

Outlook

The use of rare earths, especially in automotive pollution catalysts, permanent magnets, and rechargeable batteries, is expected to continue to increase as future demand for automobiles, computers, electronics, and portable equipment grows. Rare-earth markets are expected to require greater amounts of higher purity mixed and separated products to meet the demand. Strong demand for cerium and neodymium for use in automotive catalytic converters and permanent magnets is expected to continue throughout the decade. Future growth is forecast for rare earths in rechargeable Ni-MH batteries, fiber optics, and medical applications that include magnetic resonance imaging (MRI) contrast agents, positron emission tomography (PET) scintillation detectors, medical isotopes, and dental and surgical lasers. Long-term growth is expected for rare earths in magnetic refrigeration alloys.

World reserves are sufficient to meet forecasted world demand well into the 21st century. Several very large rare-earth deposits in Australia and China (for example, Mianning in China, and Mount Weld in Australia) have yet to be fully developed because world demand is currently being satisfied by existing production. World resources should be adequate to satisfy demand for the foreseeable future.

Domestic companies have shifted away from using naturally occurring radioactive rare-earth ores. This trend has had a negative impact on monazite-containing mineral-sands operations worldwide. Future long-term demand for monazite, however, is expected to increase because of its abundant supply and its recovery as a low-cost byproduct. The cost and space to dispose of radioactive waste products in the United States are expected to continue to increase, severely limiting domestic use of low-cost monazite and other thorium-bearing rare-earth ores.

World rare-earth markets are expected to continue to be very competitive in competing with China’s lower wages, inexpensive utilities, and fewer environmental and permitting requirements. China is expected to remain the world’s principal rare-earth supplier. Economic growth in several developing countries will provide new and potentially large markets in Southeast Asia and Eastern Europe.

The long-term outlook is for an increasingly competitive and diverse group of rare-earth suppliers. As research and technology continue to advance the knowledge of rare earths and their interactions with other elements, the economic base of the rare-earth industry is expected to continue to grow. New applications are expected to continue to be discovered and developed.

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TABLE 1

SALIENT U.S. RARE EARTH STATISTICS[1]

(Metric tons of rare-earth oxides unless otherwise specified)

	1998	1999	2000	2001	2002
Production of rare-earth concentrates[2]	5,000 [e]	5,000 [e]	5,000 [e]	5,000 [e]	5,000 [e]
Exports:					
Cerium compounds	4,640	3,960	4,050	4,490 [r]	2,970
Rare-earth metals, scandium, yttrium	724	1,600	1,650	891 [r]	1,310
Ores and concentrates	--	--	--	--	--
Rare-earth compounds, organic or inorganic	1,630	1,690	1,760	1,680 [r]	1,430
Ferrocerium and pyrophoric alloys	2,460	2,360	2,300	2,540 [r]	2,860
Imports for consumption:[e]					
Monazite	--	--	--	--	--
Cerium compounds	4,940	5,970	6,450	3,870 [r]	2,540
Ferrocerium and pyrophoric alloys	117	120	118	118	89
Metals, alloys, oxides, other compounds	8,950	17,200	17,300	15,200	11,600
Prices, yearend, per kilogram:					
Bastnasite concentrate, rare-earth oxides basis	$4.19 [e]	$4.85 [e]	$5.51 [e]	$5.51 [e]	$5.51 [e]
Monazite concentrate, rare-earth oxides basis	$0.73	$0.73 [e]	$0.73 [e]	$0.73 [e]	$0.73 [e]
Mischmetal, metal basis	$16.00 [3]	$16.00 [3]	$16.00 [3]	$16.00 [3]	$16.00 [3]
Employment, mine and mill	NA	NA	NA	NA	NA

[e]Estimated. [r]Revised. NA Not available. -- Zero.

[1]Data are rounded to no more than three significant digits, except prices.

[2]Comprises only the rare earths derived from bastnasite as obtained from Molycorp, Inc.

[3]Source: Elements, TradeTech, Denver, CO.

TABLE 2
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS[1]

(Percentage of total rare-earth oxide)

Rare earth	Bastnasite: Mountain Pass, CA, United States[2]	Bastnasite: Bayan Obo, Inner Mongolia, China[3]	Monazite: North Capel, Western Australia[4]	Monazite: North Stradbroke Island, Queensland, Australia[5]	Monazite: Green Cove Springs, FL, United States[6]	Monazite: Nangang, Guangdong, China[7]
Cerium	49.10	50.00	46.00	45.80	43.70	42.70
Dysprosium	trace	0.1	0.7	0.60	0.9	0.8
Erbium	trace	trace	0.2	0.2	trace	0.3
Europium	0.1	0.2	0.053	0.8	0.16	0.1
Gadolinium	0.2	0.7	1.49	1.80	6.60	2.00
Holmium	trace	trace	0.053	0.1	0.11	0.12
Lanthanum	33.20	23.00	23.90	21.50	17.50	23.00
Lutetium	trace	trace	trace	0.01	trace	0.14
Neodymium	12.00	18.50	17.40	18.60	17.50	17.00
Praseodymium	4.34	6.20	5.00	5.30	5.00	4.10
Samarium	0.8	0.8	2.53	3.10	4.90	3.00
Terbium	trace	0.1	0.035	0.3	0.26	0.7
Thulium	trace	trace	trace	trace	trace	trace
Ytterbium	trace	trace	0.1	0.1	0.21	2.40
Yttrium	0.10	trace	2.40	2.50	3.20	2.40
Total	100	100	100	100	100	100

Rare earth	Monazite: Eastern coast, Brazil[8]	Monazite: Mount Weld, Australia[9]	Xenotime: Lahat, Perak, Malaysia[2]	Xenotime: Southeast Guangdong, China[10]	Rare earth laterite: Xunwu, Jiangxi Province, China[11]	Rare earth laterite: Longnan, Jiangxi Province, China[11]
Cerium	47.00	51.00	3.13	3.00	2.40	0.4
Dysprosium	0.4	0.2	8.30	9.10	trace	6.70
Erbium	0.1	0.2	6.40	5.60	trace	4.90
Europium	0.1	0.4	trace	0.2	0.5	0.10
Gadolinium	1.00	1.00	3.50	5.00	3.00	6.90
Holmium	trace	0.1	2.00	2.60	trace	1.60
Lanthanum	24.00	26.00	1.24	1.20	43.4	1.82
Lutetium	not determined	trace	1.00	1.80	0.1	0.4
Neodymium	18.50	15.00	1.60	3.50	31.70	3.00
Praseodymium	4.50	4.00	0.5	0.6	9.00	0.7
Samarium	3.00	1.80	1.10	2.20	3.90	2.80
Terbium	0.1	0.1	0.9	1.20	trace	1.30
Thulium	trace	trace	1.10	1.30	trace	0.7
Ytterbium	0.02	0.1	6.80	6.00	0.3	2.50
Yttrium	1.40	trace	61.00	59.30	8.00	65.00
Total	100	100	100	100	100	100

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Johnson, G.W., and Sisneros, T.E., 1981, Analysis of rare-earth elements in ore concentrate samples using direct current plasma spectrometry—Proceedings of the 15th Rare Earth Research Conference, Rolla, MO, June 15-18, 1981, The rare earths in modern science and technology: New York, NY, Plenum Press, v. 3, p. 525-529.

[3]Zang, Zhang Bao, Lu Ke Yi, King Kue Chu, Wei Wei Cheng, and Wang Wen Cheng, 1982, Rare-earth industry in China: Hydrometallurgy, v. 9, no. 2, 1982, p. 205-210.

[4]Westralian Sands Ltd., 1979, Product specifications, effective January 1980: Capel, Australia, Westralian Sands Ltd. brochure, 8 p.

[5]Analysis from Consolidated Rutile Ltd.

[6]Analysis from RGC Minerals (USA), Green Cove Springs, FL.

[7]Xi, Zhang, 1986, The present status of Nd-Fe-B magnets in China—Proceedings of the Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producers Conference, Clearwater, FL, March 2-4, 1986: Clearwater, FL, Gorham International Inc., 5 p.

[8]Krumholz, Pavel, 1991, Brazilian practice for monazite treatment: Symposium on Rare Metals, Sendai, Japan, December 12-13, 1991, Proceedings, p. 78-82 (preprint).

[9]Kingsnorth, Dudley, 1992, Mount Weld A new source of light rare earths—Proceedings of the TMS and Australasian Institute of Mining and Metallurgy Rare Earth Symposium, San Diego, CA, March 1-5, 1992, Proceedings: Sydney, Australia, Lynas Gold NL, 8 p.

[10]Nakamura, Shigeo, 1988, China and rare metals—Rare earth: Industrial Rare Metals, no. 94, May, p. 23-28.

[11]Introduction to Jiangxi Rare-Earths and Applied Products, 1985, Jiangxi Province brochure: International Fair for Rare Earths, Beijing, China, September 1985, 42 p. (in English and Chinese).

TABLE 3
RARE-EARTH OXIDE PRICES IN 2002

Product (oxide)	Purity (percentage)	Standard package quantity (kilograms)	Price (dollars per kilogram)
Cerium	96.00	25	19.20
Do.	99.50	900	31.50
Dysprosium	99.00	3	120.00
Erbium	96.00	2	155.00
Europium	99.99	1	990.00 [1]
Gadolinium	99.99	3	130.00
Holmium	99.90	10	440.00 [2]
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	3,500.00
Neodymium	95.00	20	28.50
Praseodymium	96.00	20	36.80
Samarium	99.90	25	360.00
Do.	99.99	25	435.00
Scandium	99.99	1	6,000.00
Terbium	99.99	5	535.00
Thulium	99.90	5	2,300.00
Ytterbium	99.00	10	340.00
Yttrium	99.99	50	88.00

[1]Price for quantity greater than 40 kilograms is $900.00 per kilogram.
[2]Price for quantity less than 10 kilograms is $485.00 per kilogram.

Source: Rhodia Electronics & Catalysis, Inc.

TABLE 4

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

	2001		2002	
Category and country[2]	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Cerium compounds: (2846.10.0000)				
Australia	2,740	$15,400	1,930	$32,200
Belgium	104,000	211,000	14,200	220,000
Brazil	241,000	486,000	185,000	430,000
Canada	300,000	2,640,000	358,000	4,520,000
France	121,000	401,000	4,960	289,000
Germany	518,000	1,900,000	528,000	1,490,000
Hong Kong	35,700	357,000	24,500	179,000
India	89,400	557,000	62,900	371,000
Japan	462,000	2,580,000	185,000	1,360,000
Korea, Republic of	1,080,000	4,900,000	620,000	2,600,000
Malaysia	122,000	594,000	174,000	792,000
Mexico	232,000	1,640,000	273,000	1,850,000
Netherlands	11,100	96,200	11,400	166,000
Singapore	13,600	69,900	53,200	79,400
South Africa	988	10,400	3,940	422,000
Taiwan	286,000	1,260,000	73,900	417,000
United Kingdom	386,000	703,000	98,200	387,000
Other	477,000	1,700,000	284,000	1,620,000
Total	4,490,000	20,100,000	2,960,000	17,200,000
Total estimated equivalent rare-earth oxide (REO) content	4,490,000	20,100,000	2,960,000	17,200,000
Rare-earth compounds: (2846.90.0000)				
Austria	30,000	885,000	62,000	1,580,000
Brazil	114	46,600	27,500	235,000
Canada	148,000	1,640,000	259,000	3,220,000
China	69,300	244,000	428,000	755,000
Colombia	--	--	2,430	21,000
Finland	17,200	578,000	15,400	275,000
France	77,700	403,000	17,600	527,000
Germany	43,300	1,810,000	59,900	1,880,000
India	91,200	519,000	1,640	8,310
Japan	35,100	1,800,000	57,000	6,840,000
Korea, Republic of	161,000	1,020,000	159,000	1,060,000
Mexico	50,100	422,000	36,600	467,000
Taiwan	119,000	3,510,000	62,300	1,550,000
United Kingdom	28,900	1,420,000	41,000	1,230,000
Other	812,000	4,020,000	198,000	1,940,000
Total	1,680,000	18,300,000	1,430,000	21,600,000
Total estimated equivalent REO content	1,680,000	18,300,000	1,430,000	21,600,000
Rare-earth metals, including scandium and yttrium: (2805.30.0000)				
China	12	37,200	109,000	793,000
France	1,110	34,600	1	5,900
Germany	4,780	244,000	6,260	196,000
Japan	438,000	1,520,000	652,000	1,900,000
Korea, Republic of	817	92,900	967	140,000
Taiwan	1	4,800	1	7,050
United Kingdom	1,940	281,000	1,320	208,000
Other	295,000	4,310,000	323,000	2,830,000
Total	742,000	6,520,000	1,090,000	6,080,000
Total estimated equivalent REO content	891,000	6,520,000	1,310,000	6,080,000

See footnotes at end of table.

TABLE 4--Continued
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Category and country[2]	2001 Gross weight (kilograms)	2001 Value	2002 Gross weight (kilograms)	2002 Value
Ferrocerium and other pyrophoric alloys: (3606.90.0000)				
Argentina	25,800	$161,000	--	--
Australia	1,830	58,300	13,100	$414,000
Brazil	7,740	26,100	1,190	47,000
Canada	915,000	1,790,000	822,000	2,250,000
Chile	29,700	35,500	32,900	37,000
Colombia	17,300	23,200	9,610	12,400
Costa Rica	99	6,500	--	--
France	3,540	111,000	1,120	91,200
Germany	289,000	433,000	861,000	1,540,000
Greece	33,700	74,500	43,300	65,800
Hong Kong	238,000	627,000	206,000	269,000
Italy	818	9,930	289	8,170
Japan	126,000	1,440,000	151,000	1,290,000
Korea, Republic of	3,250	85,200	2,050	74,400
Kuwait	16,500	22,000	82,300	82,200
Mexico	49,000	1,140,000	191,000	1,180,000
Netherlands	70,400	220,000	77,100	208,000
New Zealand	35,700	65,300	36,700	62,800
Saudi Arabia	--	--	13,500	17,300
Singapore	37,500	131,000	3,390	92,700
South Africa	42,800	103,000	--	--
Spain	--	--	188	16,700
Taiwan	55,600	74,100	23,000	110,000
United Arab Emirates	314,000	308,000	168,000	156,000
United Kingdom	165,000	426,000	267,000	574,000
Other	381,000	666,000	211,000	435,000
Total	2,860,000	8,030,000	3,220,000	9,040,000
Total estimated equivalent REO content	2,540,000	8,030,000	2,860,000	9,040,000

-- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States category numbers.

Source: U.S. Census Bureau.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Category and country[2]	2001 Gross weight (kilograms)	2001 Value	2002 Gross weight (kilograms)	2002 Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, oxalates: (2846.10.0000)				
Austria	59,000	$439,000	76,500	$337,000
China	4,060,000	14,000,000	2,770,000	9,050,000
France	1,240,000	6,650,000	725,000	4,420,000
Japan	288,000	6,500,000	162,000	4,980,000
Other	115,000	737,000	73,600	348,000
Total	5,760,000	28,300,000	3,800,000	19,100,000
Total estimated equivalent rare-earth oxide (REO) content	3,870,000	28,300,000	2,540,000	19,100,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent: (2846.90.4000)				
China	107,000	1,560,000	57,300	858,000
France	14,300	305,000	4,680	160,000
Germany	--	--	10	10,100
Japan	8,190	2,420,000	11,100	2,820,000
United Kingdom	262	9,340	--	--
Other	30	15,600	238	25,400
Total	130,000	4,310,000	73,300	3,870,000
Total estimated equivalent rare-earth oxide (REO) content	77,900	4,310,000	44,000	3,870,000
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides: (2846.90.8000)				
Austria	38,900	1,300,000	75,200	1,550,000
China	8,850,000	31,000,000	5,670,000	18,700,000
Estonia	900,000	769,000	1,270,000	1,510,000
France	1,820,000	11,400,000	1,600,000	11,800,000
Germany	42,000	1,280,000	13,600	635,000
Hong Kong	--	--	65,000	169,000
Japan	302,000	7,550,000	231,000	3,780,000
Norway	34,500	14,800,000	1,730	2,520,000
Russia	124,000	196,000	571,000	1,140,000
Taiwan	18,000	48,900	9	5,750
United Kingdom	41,900	4,600,000	157,000	6,480,000
Other	26,000	195,000	25,200	916,000
Total	12,200,000	73,000,000	9,670,000	49,200,000
Total estimated equivalent REO content	9,150,000	73,000,000	7,260,000	49,200,000
Mixtures of rare-earth oxides except cerium oxide: (2846.90.2010)				
Austria	--	--	4,230	97,600
China	2,030,000	8,160,000	1,010,000	3,220,000
France	3	2,050	740	66,600
Germany	1,740	93,300	--	--
Japan	7,160	655,000	19,700	994,000
Russia	301	141,000	336	36,100
United Kingdom	386	14,300	4,600	52,300
Other	5,770	89,600	1,540	47,300
Total	2,040,000	9,160,000	1,040,000	4,510,000
Total estimated equivalent REO content	2,040,000	9,160,000	1,040,000	4,510,000
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)				
China	613,000	$7,660,000	580,000	$3,130,000
Hong Kong	566	2,520	540	13,300
Japan	546,000	6,350,000	536,000	5,870,000
Russia	--	--	5	2,250
United Kingdom	16,700	278,000	10,700	403,000
Other	6,810	115,000	84,400	575,000
Total	1,180,000	14,400,000	1,210,000	9,990,000
Total estimated equivalent REO content	1,420,000	14,400,000	1,460,000	9,990,000

See foonotes at end of table.

TABLE 5--Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Category and country[2]	2001 Gross weight (kilograms)	2001 Value	2002 Gross weight (kilograms)	2002 Value
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)				
China	4,020,000	6,180,000	2,270,000	3,350,000
France	26,600	549,000	26,400	222,000
India	1,490,000	1,720,000	599,000	734,000
Israel	--	--	951,000	542,000
Japan	1,510	110,000	3,260	123,000
Netherlands	--	--	18,800	128,000
United Kingdom	20,400	101,000	18,600	89,700
Other	65,100	403,000	33,300	416,000
Total	5,620,000	9,060,000	3,920,000	5,600,000
Total estimated equivalent REO content	2,590,000	9,060,000	1,800,000	5,600,000
Ferrocerium and other pyrophoric alloys: (3606.90.3000)				
Australia	--	--	2,310	32,100
Austria	16,300	267,000	13,800	269,000
France	113,000	1,170,000	81,900	877,000
Other	3,310	33,200	2,780	38,700
Total	132,000	1,470,000	101,000	1,220,000
Total estimated equivalent REO content	118,000	1,470,000	89,500	1,220,000

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States category number.

Source: U.S. Census Bureau.

TABLE 6

RARE EARTHS: ESTIMATED WORLD MINE PRODUCTION, BY COUNTRY[1, 2]

(Metric tons of rare earth oxide equivalent)

Country[3]	1998	1999	2000	2001	2002
China	60,000	70,000	73,000	80,600	88,000
Commonwealth of Independent States[4]	2,000	2,000	2,000	2,000	2,000
India	2,700	2,700	2,700	2,700 [r]	2,700
Kyrgyzstan:					
Compounds	691 [5]	956 [5]	NA	NA	NA
Metals	6,355 [5]	5,159 [5]	7,736 [5]	3,800	100
Malaysia	282 [5]	625 [5]	446 [5]	351 [r, 5]	360
Sri Lanka	120	120	--	--	--
United States[6]	5,000	5,000	5,000	5,000	5,000
Total	77,100	86,600	90,900	94,500 [r]	98,200

[r]Revised. NA Not available. -- Zero.

[1]World totals, U.S. data, and estimated data have been rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through June 13, 2003.

[3]In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, Nigeria, North Korea, and Vietnam, but information is inadequate for formulation of reliable estimates of output levels.

[4]Does not include Kyrgyzstan; information is inadequate to formulate reliable estimates for individual producing countries, including Kazakhstan, Russia, and Ukraine.

[5]Reported figure.

[6]Comprises only the rare earths derived from bastnasite.

TABLE 7

MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons of gross weight)

Country[3]	1998	1999	2000	2001	2002
Brazil	200	200	200	200	200
India	5,000	5,000	5,000	5,000	5,000
Malaysia	517 [4]	1,147 [4]	818 [4]	510	500
Sri Lanka	200	200	--	--	--
Total	5,920	6,550	6,020	5,710	5,700

-- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through April 18, 2003.

[3]In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.

[4]Reported figure.

FIGURE 1
PRINCIPAL SOURCES OF U.S. IMPORTS OF RARE EARTHS IN 2002